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Bureau of Mines Information Circular/1985

Evaluation of Sensitive Ground Fault Interrupters for Coal Mines

By Michael R. Yenchek and Melvin N. Ackerman

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES 75TH ANNIVERSARY 1910 1985

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Yenchek, M. R. (Michael R.)

Evaluation of sensitive ground fault interrupters for coal mines.

(Information circular / United States Department of the Interior, Bureau of Mines ; 9057)

Bibliography: p. 15.

Supt. of Docs. no.: I 28.27: 9057.

1. Coal mines and mining—Electric equipment. 2. Electric circuit-breakers. I. Ackerman, Melvin N. II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 9057.

TN295.U4 [TN343] 622s [629'.8] 85-600192

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	ms	millisecond
°C	degree Celsius	μs	microsecond
Hz	hertz	mV	millivolt
h	hour	Ω	ohm
in	inch	s	second
kHz	kilohertz	V	volt
kΩ	kilohm	V•A	volt ampere
kV	kilovolt	V ac	volt, alternating current
lb	pound	W	watt
mA	milliampere	yr	year
μF	microfarad		
μH	microhenry		

EVALUATION OF SENSITIVE GROUND FAULT INTERRUPTERS FOR COAL MINES

By Michael R. Yenchek [1] and Melvin N. Ackerman [2]

ABSTRACT

Contacts with energized conductors are a major cause of electrocutions in underground coal mines. Sensitive ground fault interrupters (GFI's) installed on in-mine three-phase ac utilization circuits would probably prevent the majority of these deaths. A sensitive GFI is a protective device that detects and interrupts small deadly ground currents in the milliampere range before those currents can cause ventricular fibrillation in humans. Commercially available three-phase sensitive GFI's have not been specifically designed for application in coal mines. The Bureau of Mines therefore tested three commercial GFI models to determine their worthiness for mine power systems. GFI design and construction, transient immunity, reliability, and time-current characteristics were evaluated in laboratory tests. No commercial device was found suitable for mine use without design modifications. The tests results will serve as a basis for the development of a mineworthy sensitive GFI in ongoing Bureau research.

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INTRODUCTION

In a study completed in 1981, 307 separate accidents in the coal industry during a 3-year period were attributed to electric shock from contacts with energized conductors (1).[3] These accidents resulted in seven fatalities and the loss of over 5,000 person-days from work due to nonfatal injuries. The majority of the nonfatal injuries and nearly all the electrocutions could have been eliminated if ground fault protection, designed to protect people, had been installed on the coal mines' resistance-grounded systems.

The grounded phase protective devices presently used on these power systems are inadequate from a shock-prevention standpoint. Typical relay current pickup or response levels are in the ampere range, considerably in excess of the electrocution threshold. Increasing the sensitivity of these electromechanical devices results in undesirable nuisance tripping and unscheduled interruptions of coal production. What is needed is a sensitive GFI that identifies and interrupts the small deadly ground currents that can electrocute people, yet ignores spurious signals such as those from motor startups.

Criteria have been established for the use of sensitive GFI's on low-voltage ac utilization circuits in U.S. mines (2). These practical guidelines include specific recommendations concerning GFI design and construction, transient immunity, reliability, and time-current characteristics. This report documents tests conducted by the Bureau of Mines in accordance with these criteria using commercially available three-phase sensitive GFI's.

GROUND FAULT PROTECTION IN U.S. MINES

The majority of U.S. mine power systems employ radial distribution, wherein the supply power branches out through switchhouses and terminates at utilization points throughout the mine. The utilization system includes power centers, rectifiers, cables, motors, and the associated protective devices. It is the most troublesome part of the power system in terms of safety and reliability due to its temporary nature. As mining advances, the utilization system is stretched to its limit and then repositioned. Thus, the circuit protective devices must adapt to constantly changing conditions.

Typical ground fault protection in mining consists of high-resistance grounding and ground fault protective relaying. The resistance inserted between the system neutral and ground limits the fault current and energy dissipation. The relay monitors the circuit and removes power upon indication of a hazardous current flow. In present U.S. mining systems, the current permitted, and the current required to operate electromechanical relays, can create a personnel hazard before power is removed.

Zero-sequence or balanced-flux relaying (fig. 1) is the most reliable and most common method employed for ground fault relaying. As shown in figure 1, the phase conductors pass through the

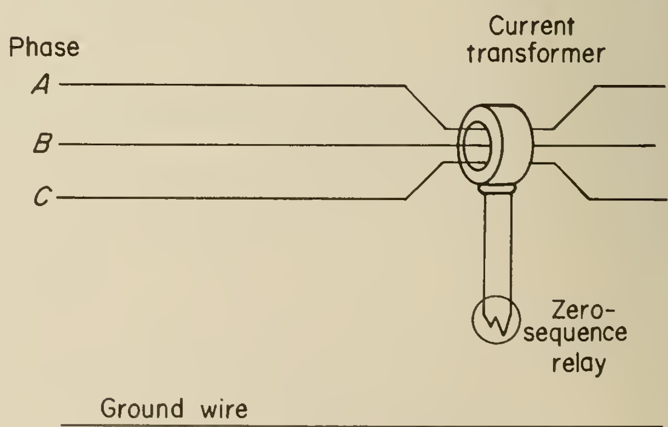


FIGURE 1. - Zero-sequence relaying.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

current transformer (CT) window. The sum of the three phase currents is the CT primary current and is proportional to the zero-sequence current (3). In an unfaulted balanced system, there is little or no zero-sequence current, and the CT secondary current is approximately zero. However, when a ground fault occurs, the resultant secondary current is used to trip a relay. Zero-sequence relaying is unaffected by phase voltage fluctuations, and, since only the ground leakage current is monitored, the relay can be made very sensitive. All of the commercial GFI's evaluated in this paper were the zero-sequence type.

DESCRIPTION OF EVALUATED GROUND FAULT INTERRUPTERS

Tests were conducted using three commercial sensitive GFI's identified under Bureau contract J0113009 (2) as having potential applicability to mining.

GENERAL ELECTRIC GROUND BREAK RELAY

The General Electric Co. (GE) type MC ground break relay (fig. 2) was

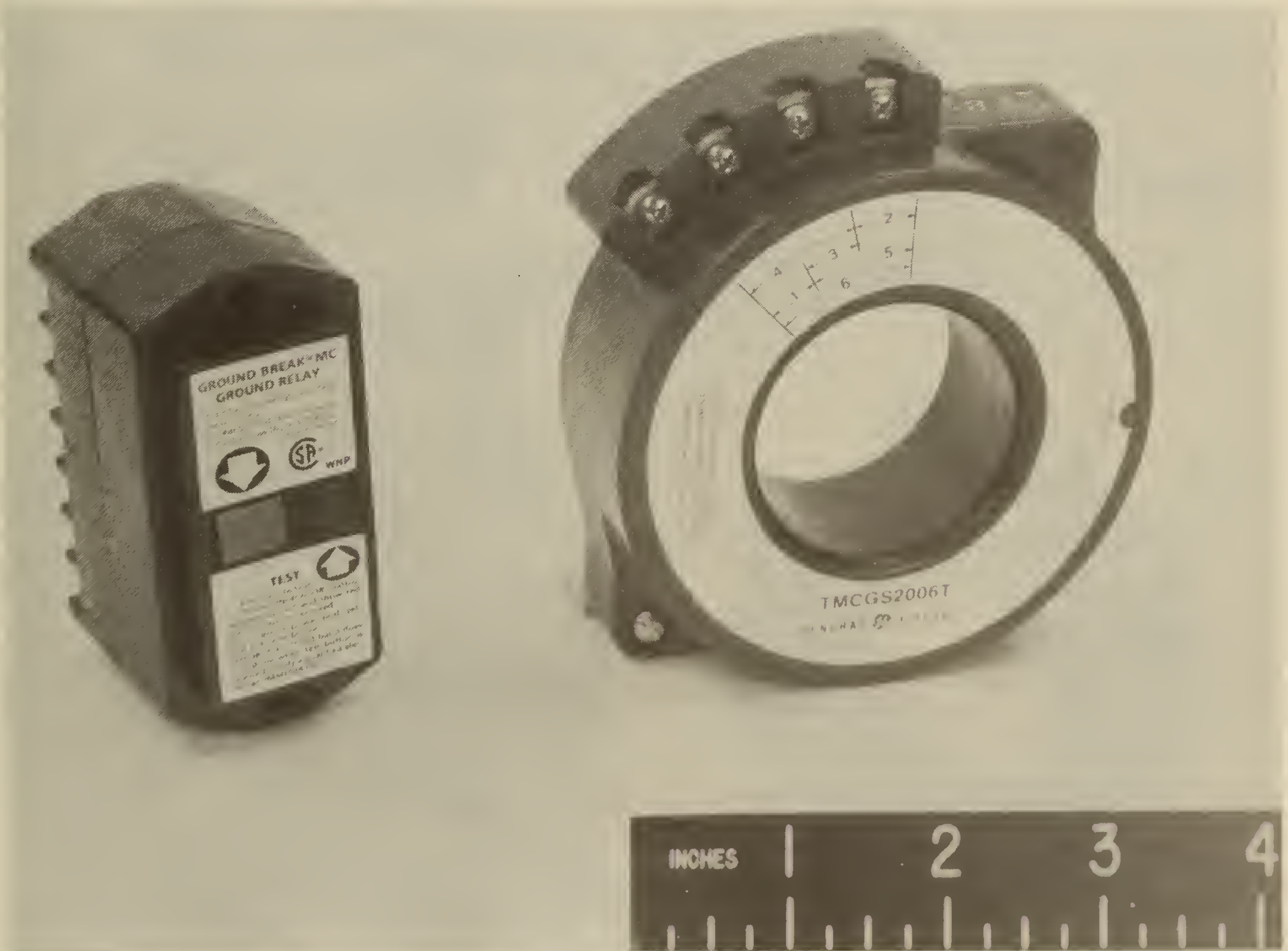


FIGURE 2. - General Electric type MC ground break relay.

specifically designed to protect motor circuits from ground faults. The TMCGS200GT current sensor provides a minimum tap setting or pickup of 100 mA. Its rated response time is 300 ms at 150% of trip level. The relay is equipped with a button for resetting following clearance of a ground fault and a button to test relay operation.

GBS HARRISON GROUND FAULT DETECTOR

The GBS Harrison Ltd. type GF2B ground fault detector (fig. 3) was developed by the National Coal Board for coal mines in the United Kingdom. It has a rated sensitivity of 90 mA ±20% at 20° C and a rated trip speed of less than 100 ms at 150% of trip current. A small light-emitting diode (LED) indicates the presence of control power to the unit. A remote pushbutton can be added for periodic testing.

MINDEL GROUND FAULT CIRCUIT INTERRUPTER

The Mindel Corp.'s model 21-7000 Shok-Blok ground fault circuit interrupter (figs. 4-5) was originally designed by Thomas Gross, a consulting engineer and holder of patents for several ground fault detection techniques. The Mindel relay has been used by the irrigation industry, but only recently has been marketed for use in coal mines. The first units tested (fig. 4) were housed in plastic boxes with a test button on the front. Some featured a knob to adjust sensitivity from 20 to 100 mA. Following failure of two original units, a newer version of the model 21-7000 was also tested (fig. 5). It consisted of a plug-in module with test and reset buttons. It had a rated sensitivity of 60 mA with a rated maximum response time of 3 s.

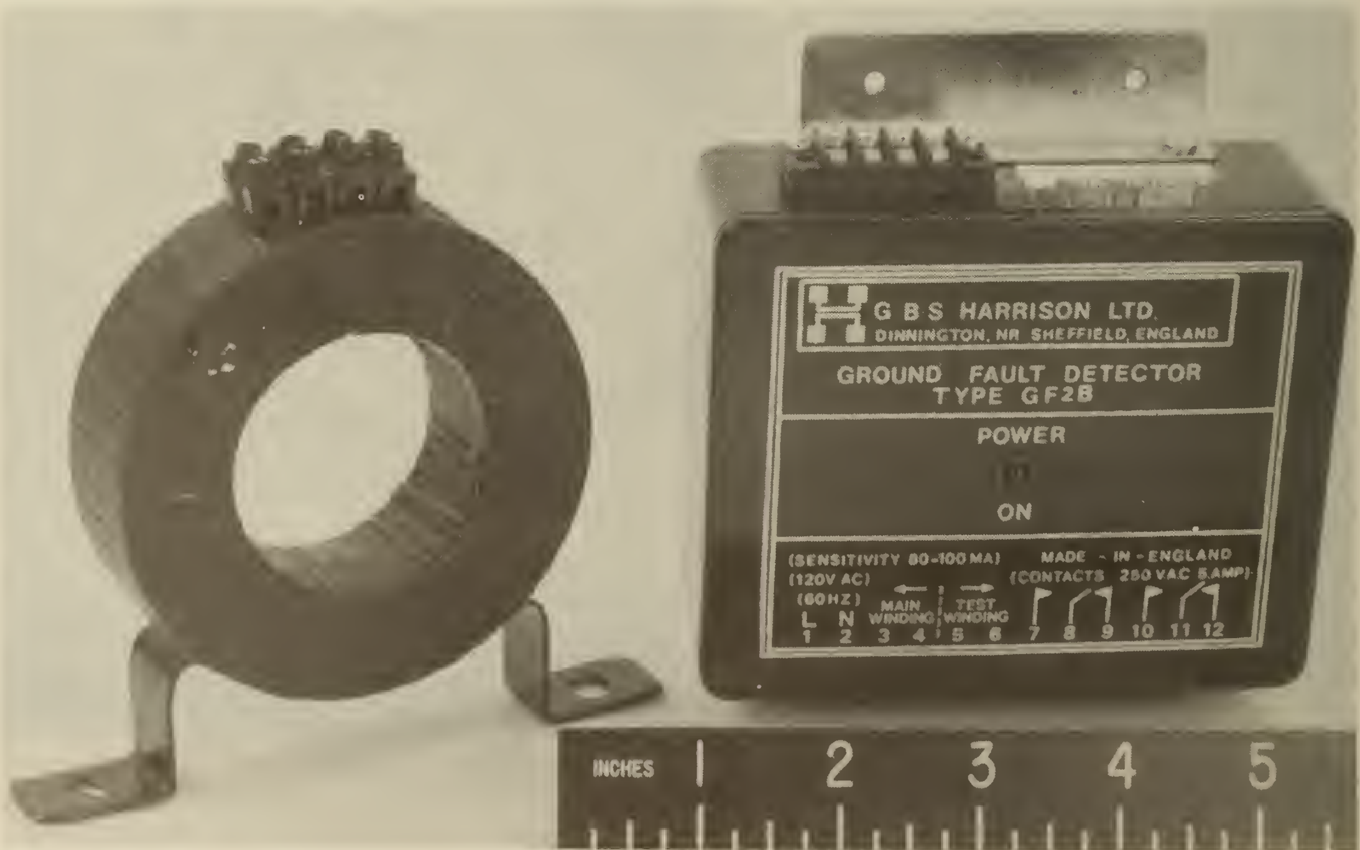


FIGURE 3. - GBS Harrison type GF2B ground fault detector.

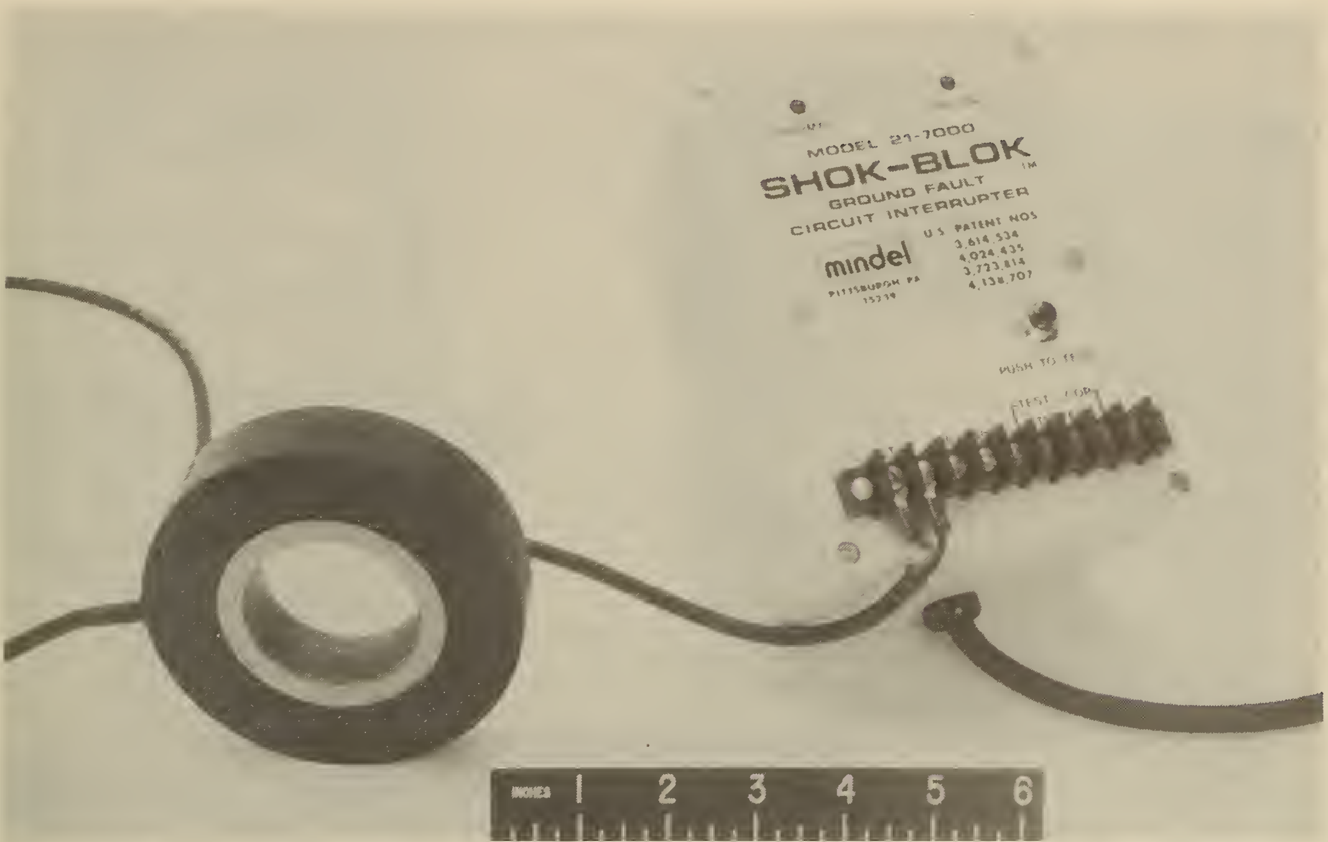


FIGURE 4. - Mindel model 21-7000 Shok-Blok ground fault circuit interrupter (older version).

TEST RATIONALES AND RESULTS

PROPER DESIGN AND CONSTRUCTION

Applicable Military Standards

Rationale

Proper design and construction will reduce the amount of downtime caused by GFI failures and thereby help bring about acceptance of the GFI as a useful safety item. Electronic instruments designed and constructed for military use must comply with Military Standard 454 (4). The following two summarized portions of that standard can be applied to GFI's used in underground mining:

Safety Hazard

The design shall incorporate methods to protect personnel from accidental contact with voltages in excess of 30 V RMS or dc during normal operation. All external surfaces shall be at ground potential during normal operation. All terminals shall be corrosion-resistant. Sharp external projections shall be avoided.

Accessibility

Suitable access shall be provided for adjustments, testing, and routine maintenance. No unsoldering shall be necessary to remove the front cover for troubleshooting.

Findings

All of the relays were housed in plastic cases, and internal adjustments were unnecessary in any of them. Only the older Mindel relay did not have exposed terminals energized at 120 V ac. Access is required to change a fuse in this relay, but the front case is easily removable without unsoldering. The relay

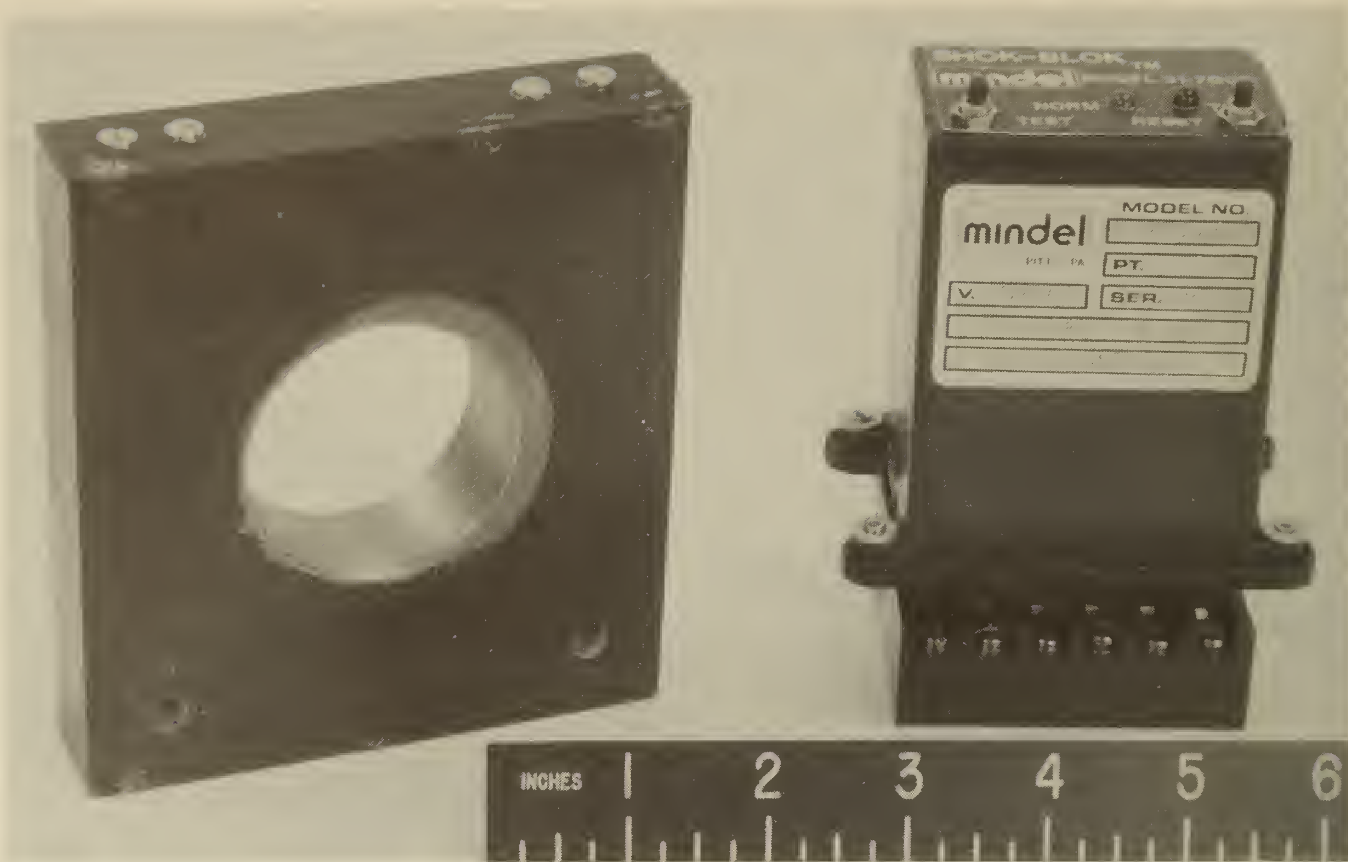


FIGURE 5. - Mindel model 21-7000 Shok-Blok ground fault circuit interrupter (newer version).

components of the newer Mindel relay were mounted in a convenient plug-in module.

The terminals on both the GE and Harrison relays corroded badly when coated with acetic acid for 24 h.

Mineworthiness

Rationale

Underground, GFI's are located inside metal-clad load centers, so both the relay and CT should have metal mounting lugs. Terminal strips should be sized for No. 12 AWG wire. In addition, the relay case should be moisture- and dust-resistant.

Findings

Only the Harrison GFI was equipped with metal lugs on both the CT and relay. However, it was also the only model with undersize wire terminals.

All relays were housed in moisture- and dust-resistant cases.

Size Limitations

Rationale

Space is limited in typical mine power equipment. Since several GFI's may be used in a single power center, they must not be much larger than present ground fault relays. Thus, the relay components should be mounted in a compact enclosure not exceeding 3 by 6 by 6 in.

To minimize leakage flux, the CT window should only be large enough to accommodate the encircled power conductors. Trailing cable size is limited to No. 4/0 AWG to facilitate handling underground. The outside diameter of a 4/0 single conductor cable is 0.807 in (5). Three such cables fit snugly through a 1.750-in-diam windows. For ease of installation of

cables with terminals, this value should be increased to 2.100 in.

Present ground fault CT's in use underground have outside diameters smaller than 4 in. Since they are placed between the molded-case circuit breaker and the load-center coupler, they are no more than 3 in wide.

Findings

The dimensions of the CT's and relays are given in figure 6. All of the CT's have undersized windows, and only the outside diameter of the GE CT did not exceed 4 in. All relay enclosures except the older Mindel were appropriately sized.

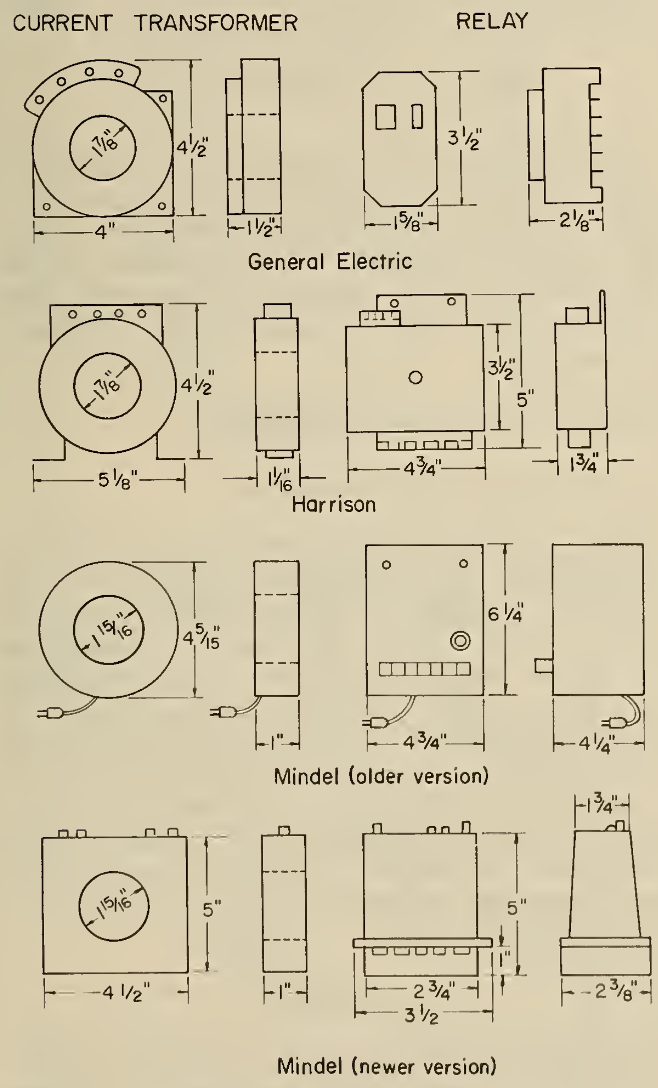


FIGURE 6. - GFI dimensions.

ELECTROCUTION PREVENTION

Tests at 60 Hz

Rationale

The primary reason for employing sensitive GFI's in mining is to prevent accidental electrocutions. The resultant cause of death in these instances is ventricular fibrillation. In this condition, the normal heartbeat stops, and the ventricles twitch irregularly. The 60-Hz threshold has been statistically defined as the current through the chest that will produce ventricular fibrillation in 1 out of 200 people. For 110-lb individuals, this threshold can be expressed as

$$I = 116/\sqrt{t} \quad (6),$$

where I is the current in milliamperes and t is the time in seconds. This relationship is shown graphically in figure 7. The safe area, to the left of the plotted line (in figure 7), is the desired region for GFI operation. It should be noted that the equation given above is only valid for shock durations of less than 5 s.

Procedure

A variable voltage source in series with a 50 Ω, 225-W fixed resistance was used to inject a 60-Hz current through each CT primary as shown in figure 8. A double-pole single-throw switch initiated the test and triggered the storage oscilloscope. Test currents were varied from 0 to 1,000 mA.

Results

The test data are listed by manufacturer in tables 1-4. The data were averaged and plotted with the ventricular fibrillation threshold superimposed, as shown in figure 9. Statistically, currents less than 50 mA should not cause ventricular fibrillation. In light of this, and since ground currents on a typical resistance-grounded system protected by a sensitive GFI would be limited to

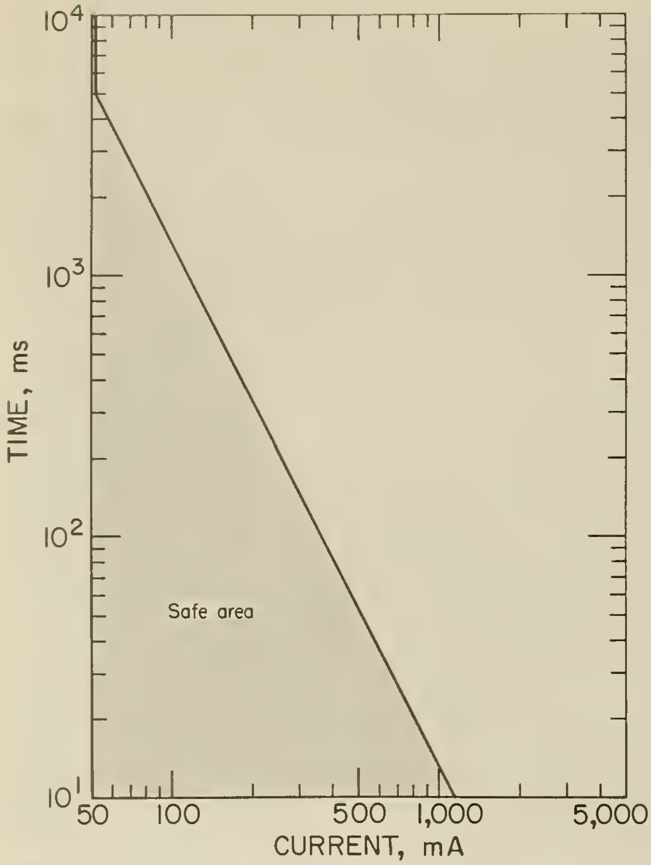


FIGURE 7. - Ventricular fibrillation threshold at 60 Hz.

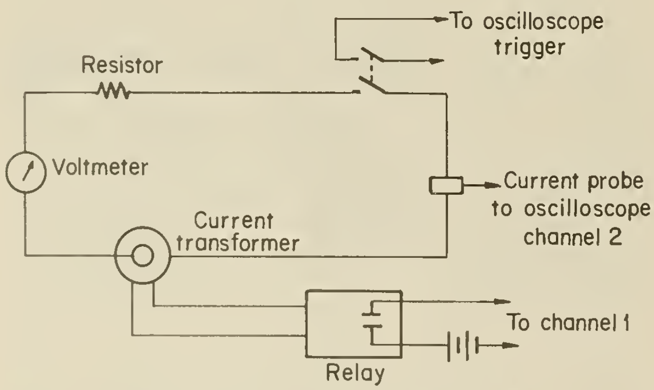


FIGURE 8. - Test setup to determine tripping characteristics at 60 Hz.

500 mA, the area of interest lies between 50 and 500 mA.

Close examination revealed that only the Mindel GFI's provided complete protection against electrocution at 60 Hz. However, the older Mindel, with a pickup of 8 mA, was judged to be overly sensitive. Both the GE and Harrison

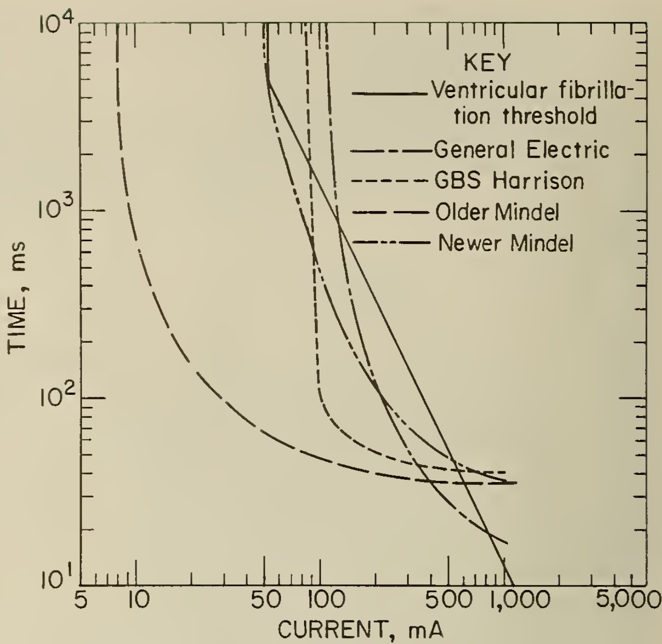


FIGURE 9. - GFI response at 60 Hz.

models lacked the sensitivity necessary for protection against 50-mA faults. The curves depict relay operation time only. To obtain the total clearing time, about 32 ms should be added, to account for opening of the molded-case circuit breaker.

Power Harmonics

Rationale

The filtering for GFI's must be designed so as to preclude false tripping by any harmonics superimposed on the power conductors. However, attenuation of these higher frequency currents must not be so severe that hazardous currents are permitted to flow. The ventricular fibrillation threshold for humans as a function of frequency has been extrapolated from experiments with animals (7). As shown in figure 10, this threshold is at a minimum at about 60 Hz and increases exponentially with frequency.

Procedure

An audio oscillator and power amplifier provided high-frequency test currents from 60 Hz to 10 kHz, as shown in figure 11. For each frequency, the voltage

TABLE 1. - General Electric: Tripping characteristics at 60 Hz

I, mA	Time, ms					
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
100[1]............	ND	ND	ND	ND	ND	ND
110..............	ND	7,200	5,400	5,700	6,000	6,700
125..............	4,700	900	1,000	1,100	900	1,200
150..............	1,000	800	350	500	350	750
200..............	100	180	120	100	200	250
300..............	70	40	40	40	50	50
500..............	30	25	23	30	40	25
800..............	20	10	15	25	30	15
1,000............	20	10	13	25	25	20

I Current. ND No data; relay did not activate.
[1]Rated sensitivity of General Electric relay.

TABLE 2. - GBS Harrison: Tripping characteristics at 60 Hz

I, mA	Time, ms					
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
90...............	540	ND	760	1,100	600	120
95...............	50	310	390	720	280	80
100..............	50	88	50	500	63	60
120..............	50	50	50	50	45	55
160..............	50	56	50	43	55	50
200..............	50	50	50	50	50	45
250..............	50	50	50	50	50	45
300..............	50	50	50	43	45	40
400..............	50	50	50	40	45	40
600..............	50	50	50	40	40	35
800..............	50	50	37	43	40	35
1,000............	50	50	40	30	35	35

I Current. ND No data; relay did not activate.

TABLE 3. - Older Mindel: Tripping characteristics at 60 Hz

I, mA	Time, ms				I, mA	Time, ms			
	Unit 1	Unit 2	Unit 3	Unit 4[1]		Unit 1	Unit 2	Unit 3	Unit 4[1]
10......	ND	ND	900	75	100.....	50	65	45	45
15......	540	560	300	35	300.....	40	50	35	35
25......	220	180	100	25	600.....	40	50	35	35
50......	75	95	65	20	1,000...	40	50	35	35

I Current. ND No data; relay did not activate.
[1]Pickup adjusted to maximum setting.

NOTE.--Units 5 and 6 failed prior to this test.

TABLE 4. - Newer Mindel: Tripping characteristics at 60 Hz

I, mA	Time, ms	I, mA	Time, ms
50...........................	ND	200.........................	150
60...........................	2,500	300.........................	80
75...........................	1,100	500.........................	45
100..........................	500	800.........................	35
150..........................	250	1,000.......................	33

I Current. ND No data; relay did not activate.

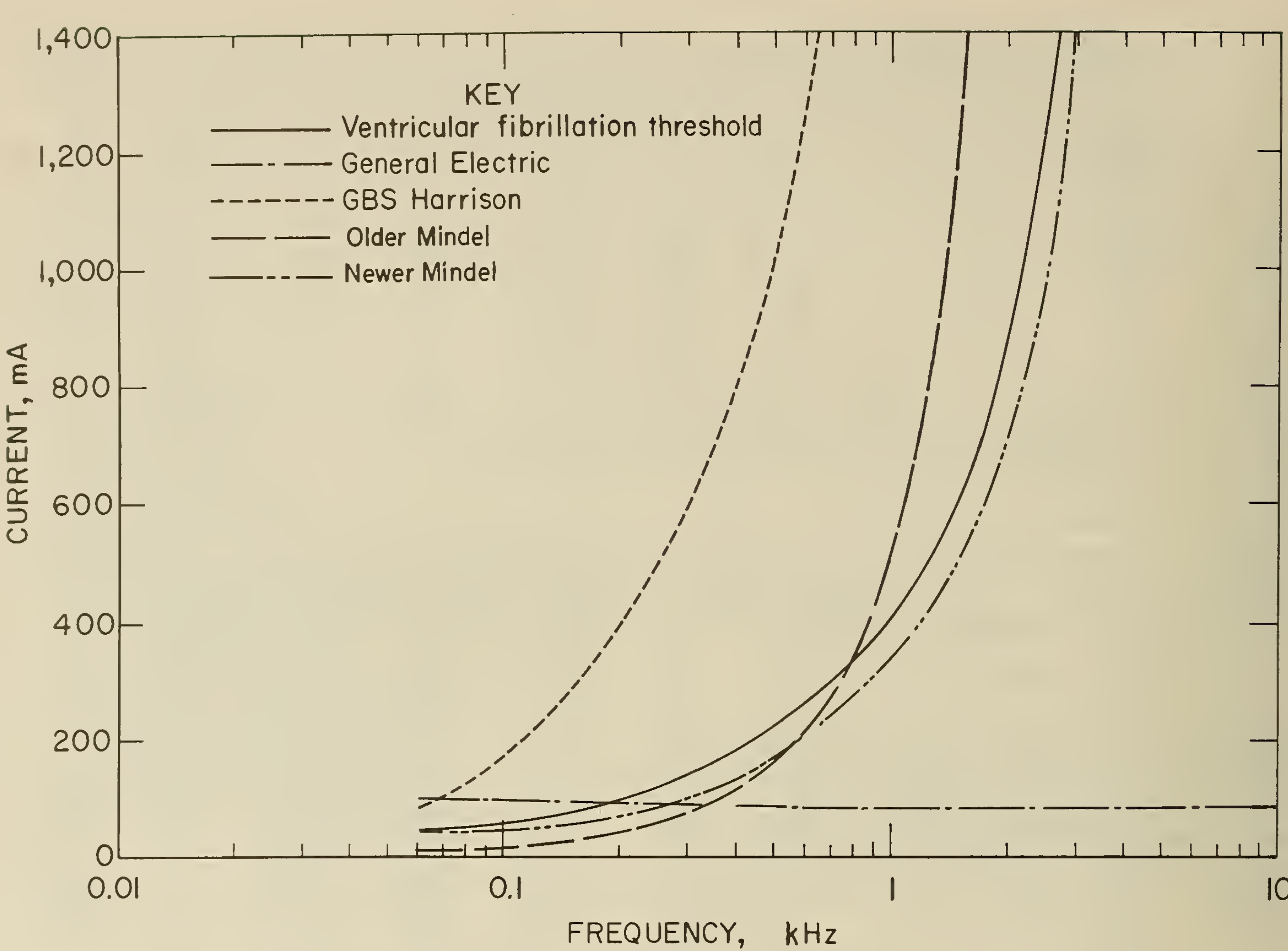


FIGURE 10. - GFI frequency response.

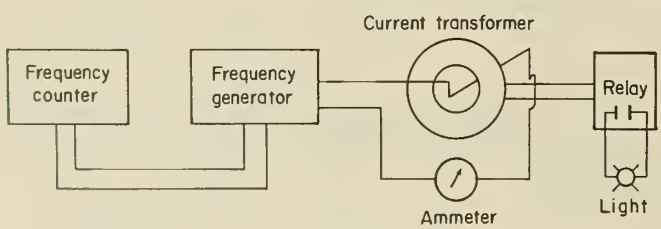


FIGURE 11. - Frequency-response test circuit.

was slowly increased until the relay activated.

Results

The test data are tabulated in tables 5-8 for each manufacturer. A plot of the averaged values for each relay is shown superimposed on the allowable attenuation curve in figure 10.

The results indicate that the filtering in the Harrison and older Mindel models attenuated higher frequency currents to the extent that ventricular fibrillation would be possible. The GE model had no filtering and yielded a flat response. The frequency characteristics of new Mindel units lie close to, but always on the safe side of, the fibrillation threshold.

TRANSIENT IMMUNITY

Voltage Surges

Rationale

Mine power systems frequently excperience voltage surges when circuit breakers and switches are opened or closed. Although the duration of these transients is quite short--a few 60-Hz cycles--past research indicates their magnitude can reach 5 per unit crest voltage at utilization levels (8). These

TABLE 5. - General Electric: Frequency response data

Freq, Hz	Current, mA					
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
60..............	112	105	105	105	100	100
100.............	100	100	100	100	95	95
500.............	80	95	90	90	85	85
1,000...........	80	90	90	90	85	85
3,000...........	80	92	90	90	85	85
5,000...........	82	95	90	90	85	90
8,000...........	80	100	95	95	90	95
10,000..........	100	105	95	95	90	95

TABLE 6. - GBS Harrison: Frequency response data

Freq, Hz	Current, mA					
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
60..............	90	95	90	85	90	90
100.............	180	180	170	160	180	180
200.............	400	390	350	320	380	380
500.............	1,000	1,050	1,000	950	1,000	1,050
800.............	1,650	1,600	1,700	1,500	1,550	1,500
1,000...........	1,950	2,000	2,000	1,900	2,000	2,000

TABLE 7. - Older Mindel: Frequency response data

Freq, Hz	Current, mA				Freq, Hz	Current, mA			
	Unit 1	Unit 2	Unit 3	Unit 4[1]		Unit 1	Unit 2	Unit 3	Unit 4[1]
60......	14	12	9.5	10	500.....	130	200	110	100
100.....	13	15	10	13	1,000...	420	700	500	450
200.....	33	40	28	31	3,000...	1,300	1,350	1,350	1,200

[1]Pickup adjusted to maximum setting.

NOTE.--Units 5 and 6 failed prior to this test.

TABLE 8. - Newer Mindel: Frequency response data

Freq, Hz	I, mA	Freq, Hz	I, mA
60..............................	55	500..............................	160
100.............................	55	1,000............................	340
200.............................	68	3,000............................	1,400

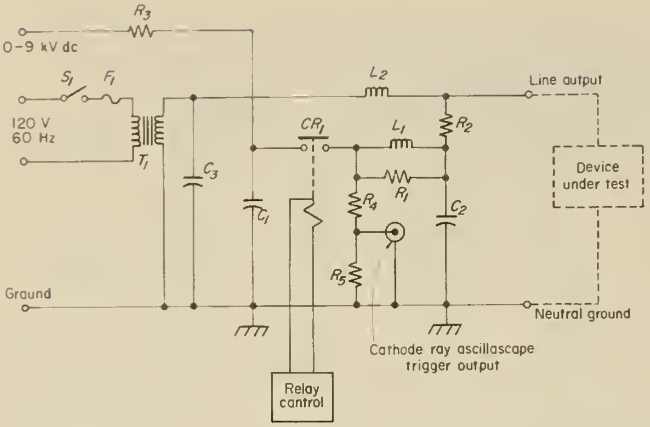
I Current.

surges, when present on the power conductors encircled by the GFI CT, should not falsely activate the relay. In addition, they should not damage the relay control circuitry.

Procedure

The impulse tester used to generate voltage transients was constructed in accordance with Section 19A of Underwriters' Laboratories' Standard 943, "Ground Fault Circuit Interrupters." Consisting of a relay switch and resonant circuit, the tester simulates transient overvoltages as they would occur on residential and industrial power systems. Schematics are shown in figures 12 and 13.

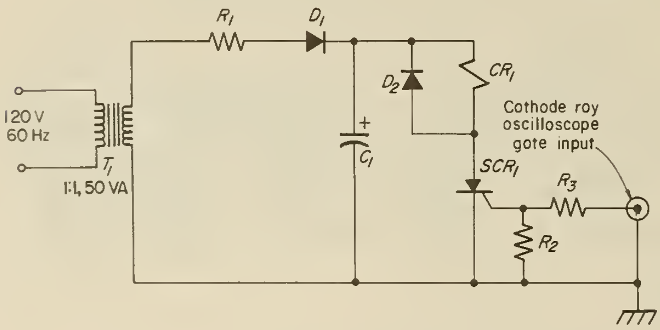
The generated waveform exhibited the following characteristics under no load: (1) initial rinse time of 0.5 μs between 10 and 90% of peak amplitude, (2) 10-μs period of following oscillatory wave,



KEY

C_1 Capacitor 0.025 μF, 10 kV
C_2 Capacitor 0.01 μF, 10 kV
C_3 Capacitor 4 μF, 400 V
L_1 Coil 15 μH (32 turns, No. 23 wire, 0.7-in-diam air core)
L_2 Coil 70 μH (28 turns, No. 23 wire, 0.6-in-diam air core)
T_1 Transformer 1:1, 500 V·A
S_1 Switch
R_1 Resistor 22 Ω, 1 W
R_2 Resistor 12 Ω, 1 W
R_3 Resistor 1.3 MΩ (12 x 110 kΩ, ½ W)
R_4 Resistor 4.7 kΩ (10 x 4.7 kΩ, ½ W)
R_5 Resistor 200 Ω, ½ W
CR_1 Relay 2 normally open poles in series GE CR2790 E 100 A2
F_1 Fuse 3 A

FIGURE 12. - Basic impulse generator circuit.



KEY

R_1 Resistor 10 kΩ, 1 W
R_2, R_3 Resistor 1 kΩ, ½ W
C_1 Capacitor 32 μF, 250 V
D_1, D_2 Diode 1N5060
SCR_1 Thyristor GE C122B
CR_1 Relay GE CR2790 E 100 A2
T_1 Transformer Triad N4S X

FIGURE 13. - Relay control circuit for impulse generator.

and (3) amplitude of each successive peak 60% of the preceding peak. The amplitude of the first peak was fully adjustable from 0 to 8,000 V. In the first part of the test, ten successive 5-kV surges were imposed on the power conductors encircled by the CT while the relay contacts were observed. Next, ten 1-kV impulses were applied in parallel with the 120-V ac control voltage and at random with respect to its phase. Afterward, relay operation at 60 Hz was checked to confirm possible circuit damage.

Results

Application of the 5-kV surge did not affect the GE and Harrison relays. However, the Mindel relays were activated momentarily following each impulse. This may be attributed to their lower pickup. All relays operated satisfactorily following the 1-kV surge to the control circuits.

Common Mode Transients

Rationale

Sensitive GFI's used on coal mine power systems must be unaffected by the large transient currents common to all phases of ac utilization circuits. Such currents may briefly exceed six times full motor rating during startup or heavy intermittent loading. The maximum short-circuit settings listed in 30 CFR 75.601 effectively limit balanced three-phase loading to 2,500 A. Nevertheless, balanced currents up to 2,500 A should be tolerated for up to 5 s without actuation of the relay.

Procedure

The motor test station in the Bureau's Pittsburgh, PA, Mine Electrical Laboratory was used to variably supply balanced three-phase currents through a trailing cable encircled by the GFI CT. The load consisted of three 0.3 Ω resistors connected in a delta configuration. The supply voltage was gradually increased until the relay activated or the 2,500-A ceiling was reached. Tripping thresholds were confirmed through repeated tests.

Results

Only the Harrison relay was immune to common mode transients. All the GE units tripped at between 200 and 250 A, while the older Mindel GFI's required only 125 to 200 A to operate. The newer Mindel relay did not actuate until 1,700 A was reached.

Current Withstand

Rationale

The molded-case circuit breakers used on low-voltage ac mine power circuits typically have an interrupting rating of 30,000 A. Currents near this magnitude are quite possible for three-phase faults. Since the GFI CT is a part of the power system, it too must withstand up to 30,000 A for the time it takes the breaker to clear (a few cycles).

Procedure

The withstand test was conducted using a high-current circuit breaker tester, as shown in figure 14. The tester was equipped with an initiate switch that could be jogged to reasonably control the test duration. Current magnitudes were recorded on a storage oscilloscope connected across a 400-A, 100-mV shunt. The CT secondaries were shorted to preclude high secondary voltages. Each was subjected to 30,000 A for approximately 4 cycles. The 60-Hz current ratios and winding resistances were measured before and after the withstand test to detect any degradation of the CT.

Results

The winding resistance and current ratios listed in tables 9 and 10 did not change after the withstand test. This indicates that all the CT's safely tolerated 30,000 A for the time it took the breaker to clear.

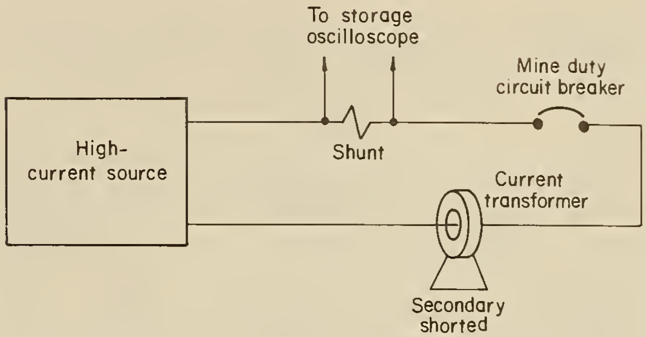


FIGURE 14. - Current withstand test circuit.

RELIABILITY

Quality Assurance

Rationale

For dependability underground, all devices made by the same manufacturer should operate in the same manner and have a reasonable service life. In

TABLE 9. - Winding resistance, Ω

Unit	GE	GBS Harrison	Older Mindel	Newer Mindel
1.........	0.5	1.3	1.2	1.3
2.........	.6	1.3	1.3	NAp
3.........	.5	1.4	1.2	Nap
4.........	.5	1.4	1.3	NAp
5.........	.5	1.4	1.2	NAp
6.........	.5	1.3	1.7	NAp

NAp Not applicable.

TABLE 10. - Current ratio tests (secondary shorted), mA

Manufacturer	Primary	Secondary					
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
General Electric...........	50	0.13	0.38	0.38	0.38	0.38	0.39
	500	3.68	4.02	4.03	4.07	4.06	4.07
GBS Harrison...............	50	.13	.18	.13	.13	.13	.13
	500	1.63	1.64	1.63	1.64	1.64	1.64
Mindel (older version)......	50	.71	.68	.68	.71	.71	.70
	500	6.91	6.92	6.92	6.92	6.92	6.91
Mindel (newer version)......	50	.35	ND	ND	ND	ND	ND
	500	5.02	ND	ND	ND	ND	ND

ND No data.

addition, each GFI should be equipped with a means to test its operation.

Results

There was considerable conformity in the frequency response data for all units. However, the time versus current results correlated well only above 150% of pickup. The older Mindel relays were judged to be unreliable, as two of the original six units purchased failed during the test program. Quality assurance judgments of the newer version could not be made since only one unit was tested. All of the relays evaluated featured test circuits to simulate ground faults.

Safe Failure Modes

Rationale

In the event of failure of the GFI's internal circuitry, the unit should react to remove power, to prevent a false sense of security. Two common failure modes are loss of 120-V ac control power to the GFI and opening of the CT winding.

Results

Only the GE relays failed to operate when control power was removed or the CT winding opened.

SUMMARY AND CONCLUSIONS

Results of the sensitive GFI tests are summarized in table 11. They show that none of the commercial three-phase GFI's evaluated is suitable for underground mining without design modifications.

Overall, the newer Mindel GFI came closest to compliance with the established criteria. Increasing the number of secondary turns on the Mindel CT would probably eliminate any false tripping during motor startups (common mode). False tripping due to voltage surges on the power conductors may be eliminated by (1) increasing the CT burden impedance or (2) changing the rating of the back-to-back diode shunt that protects against transients coupled through the CT's. The unreliability of the older Mindel unit

TABLE 11. - Summary of results

	General Electric	GBS Harrison	Older Mindel	Newer Mindel
Military standard compliance (terminals).	Not corrosion-resistant.	Not corrosion-resistant.	Exposed at 120 V ac.	Passed.
Mineworthiness........	Lacked metal mounting lugs.	Undersize wire terminals.	Lacked metal mounting lugs.	Lacked metal mounting lugs.
Proper dimensions.....	CT ID too small; relay OK.	CT inadequate; relay OK.	CT OD and relay oversized.	CT OD too large; relay OK.
Electrocution prevention at 60 Hz.	Pickup too high.	Pickup too high.	Too sensitive..	Passed.
Power harmonics.......	May nuisance trip.	Too much attenuation.	Too much attenuation.	Do.
Voltage surges........	Passed, but pickup high.	Passed, but pickup high.	False tripped..	False tripped.
Common mode...........	Failed.........	...do.........	Failed; too sensitive.	Failed.
Current withstand.....	Passed.........	Passed........	Passed........	Passed.
Quality assurance.....	...do..........	...do.........	Failed........	Not determined.
Safe failure modes....	Failed.........	...do.........	Passed........	Passed.

and its extreme sensitvity preclude its use in underground coal mines.

Both the GE and Harrison GFI's require many modifications to pass the tests. Both must be made more sensitive to detect 50 mA faults. The GE CT should be wound regressively for common mode immunity. The filtering of the Harrison relay should be modified to detect hazardous high-frequency currents.

The results of these tests are intended to serve as a basis for the development of a mineworthy, sensitive GFI in ongoing Bureau research. Such a device could be expected to prevent nearly all electrocutions on coal mine ac utilization circuits.

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